



Bioadsorption of some heavy metals by selected bacterial isolates from solid waste dumpsites

Kingsley Erhons ENERIJIOFI,^{*1,2} Esther ADEBARI,¹ Taiwo Stephen OKANLAWON,¹ Henrietta Omokhele OBUEH³

¹Department of Biological Sciences, College of Basic and Applied Sciences, Glorious Vision University (formerly Samuel Adegboyega University), Ogwa, Edo State, Nigeria

* e-mail: kingsleyenerijiofi@gmail.com

²Centre for Research and Innovation, Academy of Maritime Education and Training Deemed to be University, Kanathur, Chennai, India

³Department of Biological Sciences, College of Science and Computing, Wellspring University, Benin City, Edo State

Abstract: The effect of heavy metals is dangerous to the ecosystem because these substances are non-biodegradable. This research paper assessed the bioadsorption capacity of bacterial isolates of metal dump soils in Ebelle, Igueben Local Government Area, Edo State. Standard bacteriological analysis was done on three soil samples. Isolates were *Staphylococcus aureus*, *Bacillus subtilis*, *Enterococcus faecalis*, and *Escherichia coli*. The use of CuSO_4 , $\text{K}_2\text{Cr}_2\text{O}_7$, FeCl_3 , and ZnSO_4 in bio-adsorption tests indicated that the different isolates displayed varied bio-adsorption potentials. Overall, *Bacillus subtilis* displayed the highest adsorption capacity in the removal of heavy metals in contaminated soils with 60.61% for FeCl_3 and 62.87% for ZnSO_4 respectively. The study recommends the use of *Bacillus subtilis* as sustainable and eco-friendly alternative to heavy metal removal in the environment.

Keywords: *Bacillus subtilis*, environmental sustainability, bioremediation, environmental safety and health

1. Introduction

Since the fast rate of urbanization brought on by the wastewater discharges from factories, chemical plants, and treatment facilities for waste, as well as the extensive use of fertilizers and pesticides, among other factors, pollutants in the environment with hazardous heavy metals is rising every day on a global scale

[1]. One major environmental problem is the contamination of soil and aquatic habitats by heavy metals [2, 3]. These elements typically have a specific gravity of more than 5.0 g/cm³, which is five times the density of water. Heavy metal pollution is seriously harming both the environment and human health due to its non-biodegradability, low solubility, and toxicity, which can induce cancer and lead to mutagenic consequences at low concentrations [4]. Metals such as mercury, lead, and arsenic can be toxic, leading to weakness, headaches, abdominal cramps, diarrhoea, anaemia, and eventual kidney and brain damage [5, 6]. A metal such as cadmium is extremely toxic and has been shown to induce DNA breakage, resulting in the deterioration of biological functions [7]. Mercury at a concentration as low as 0.0010mg/L is very toxic.

Numerous microorganisms found in soil are crucial to the sustained development and nutrient cycle of the biosphere [8]. Because of its high efficiency, low cost, and environmental benefits, the bioremediation of hazardous metals from polluted soil and wastewater using bacteria is attracting increasing attention [9]. Accordingly, microorganisms have developed a variety of defence mechanisms against metal uptake. These include the conversion of hazardous metal to less toxic forms, the release of metal outside the bacterial cell, and the storage of metal inside the bacterial cell [1, 10]. However, both conventional chemical restoration techniques based on curing and leaching as well as ecological restoration techniques based on adsorption and transfer are used to treat heavy metal pollution in soil [11].

Numerous methods, such as precipitation, adsorption, ion exchange, membrane, and electrochemical technologies, have been developed to treat metal-bearing industrial effluents. However, these methods are extremely costly, unfriendly to the environment, and largely dependent on the waste concentration, making them ineffective in diluted solutions. Therefore, this work is aimed at providing a cheap, non-toxic, and still sustainable method using selected bacterial isolates to remediate heavy metals from soil environment.

2. Materials and methods

Description of the study area

The dumpsite is situated in Ebelle, Igueben Local Government Area of Edo State, which lies at latitude 6°30' 20.16" N and longitude 6°12' 30.24" E. There are dumpsites that are unauthorized by the Edo Government and that serve as disposal sites for solid wastes of agricultural, domestic, and commercial origin from traders and residents. The refuse contains bottles, metallic scraps, leather, and iron scraps. Residential buildings are erected near the dumpsites and have been occupied for decades. Disposal of refuse, spent oil, industrial

waste, and vehicular emissions are major pollutants within the vicinity of the sample collection.

Collection of the sample

The soil samples selected for this study have been exposed to metal scraps dumping for over a decade. Triplicate soil samples were obtained from three different locations within the dumpsite at a depth of 0–20 cm and transported to the laboratory for immediate processing. Labelled sterilized dark-coloured plastic containers were used to gather one batch for physicochemical and heavy metal analyses and a marked sterilized top-cap container to collect the other batch for microbiological examination.

Determination of soil physicochemical and heavy metal parameters

This was done using the method as described by [12]. The physicochemical parameters analysed included pH, particles size, organic carbon, organic matter, exchangeable acidity (Al^{3+} and H^+), exchangeable cations (Na^+ , K^+ , Ca^{2+} , Mg^{2+}), nitrogen, and phosphorus contents. Twenty (20) grams of soil sample was weighed in 50 ml and added to 20 ml of distilled water in a beaker. The mixture was stirred intermittently for 30 minutes and then filtered. The pH was measured with a standardized pH metre and recorded [13]. The hydrometer method was used to determine the particle sizes [14, 15]. In an extraction bottle, 50 g of oven-dried soil was mixed with 100 ml of Calgon, and the mixture was left to soak for half an hour. The soil suspension was moved into a sedimentation cylinder and filled to the 100 ml mark with distilled water after the mixture had been agitated with a mechanical stirrer. In order to fully mix the contents, a plunger was inserted and moved up and down. The upward strokes of the plunger towards the bottom helped to remove the silt. After gently lowering the hydrometer into the suspension, readings were obtained 40 seconds later (R40 sec.). At 120 minutes, the second reading was obtained. The percentage of silt and clay is represented by the first (R40 sec.) reading, whereas the percentage of clay is represented by the second. % sand is calculated by adding % silt + clay and subtracting % clay from 100. The Percentage Organic Carbon has been determined using methods adopted from previous studies [13]. The organic matter was calculated by multiplying the organic carbon amount by 1.724. The titration method was used to measure exchangeable acidity (Al^{3+} and H^+), whereas a flame photometer was used to measure exchangeable cations (Na, K, Ca, and Mg). The Kjeldahl Method Black was used to determine the nitrogen concentration.

Available phosphorus determined by using the Bray P-1 method

Heavy metal determination

The approach of [12] was used to analyse the heavy metals. The soil samples were pulverized using a ceramic mortar and pestle after being air dried in the lab to a constant weight. To remove debris, the soil samples were sieved using a 2-mm mesh screen. A 1:10 ratio of HNO₃ to HCl was used to digest two grams (2 g) of the sample. After adding twenty-five millilitres (25 ml) of distilled water to the mixture, it was heated for twenty minutes in a water bath to achieve a milky hue. After being taken off the heat, they were allowed to cool before being put into 50-ml sample vials and filled with distilled water to the 25 ml mark. The Atomic Absorption Spectrophotometer (AAS), model PG 550, was used to measure the concentrations of heavy metals, while the Jenway flame photometer, model PFP7, was used to measure the concentrations of sodium, potassium, calcium, and magnesium.

Microbiological analysis

Soil sample preparation

The soil samples collected were taken to the laboratory and air dried for a period of 48 hours. The samples were grounded and sieved using a 2-mm sieve to remove dirt and plant debris.

Bioadsorption experiment

In a 250-ml Erlenmeyer flask, various quantities of pure and mixed biomass cultures were mixed with 100 ml of metal solution. The flasks were allowed to equilibrate while being shaken at a steady 300 rpm. At the conclusion of the investigation, samples were gathered, centrifuged as described above, and spectrophotometry was used to measure the amount of metal in the supernatant [16].

Analytical estimation of heavy metals (CuSO₄, K₂Cr₂O₇, FeCl₃, ZnSO₄)

In 50% acetone, a 0.25% w/v solution of diphenyl carbazide was prepared. The sample solutions, which included varied amounts of the individual metals, were pipetted out into 25 ml standard flasks in 15 ml increments. After adding 2 millilitres of 3 molar H₂SO₄ and 1 millilitre of diphenyl carbazide, the volume was increased to 25 millilitres using deionized, double-distilled water, resulting

in final concentrations between 0.15 and 0.3 parts per million. A UV-visible spectrophotometer was used to measure the amounts of the various metals. At the maximum wavelength of 540 nm, the absorbance was measured in comparison to a reagent blank. In the concentration range under investigation, a linear plot demonstrating adherence to the Beer–Lambert law was produced [17].

$$\text{Percentage biosorption} = \frac{\text{Initial} - \text{Final metal concentration}}{\text{Initial metal concentration}} \times 100\%$$

3. Results and discussion

Table 1 shows the mean total heterotrophic bacterial count. Total heterotrophic bacteria count for R1 ranged from 6.8×10^4 to 7.6×10^4 , *Staphylococcus aureus* for R1 ranged from 4×10^2 to 1×10^3 , and Mannitol salt agar count ranged from 8×10^2 to 2.2×10^3 .

Table 1. Results of heterotrophic bacterial count

	TOTAL Heterotrophic bacterial count		<i>Staphylococcus aureus</i> count		MSA count	
	R1	R2	R1	R2	R1	R2
Soil A	7.2×10^4	7.2×10^4	1×10^3	1×10^3	2.2×10^3	2.2×10^3
Soil B	6.8×10^4	6.8×10^4	7×10^2	7×10^2	1.4×10^3	1.4×10^3
Soil C	7.6×10^4	7.6×10^4	4×10^2	4×10^2	8×10^2	8×10^2

Note: MSa = mannitol salt agar.

Table 2 reveals the bacteria isolates identified in this study, which include *Staphylococcus aureus*, *Bacillus subtilis*, *Enterococcus faecalis*, and *Escherichia coli*.

Table 2. Prevalence of bacteria isolates

SOURCE	<i>Staphylococcus aureus</i>	<i>Bacillus subtilis</i>	<i>Enterococcus faecalis</i>	<i>Escherichia Coli</i>
Soil A	+	+	+	+
Soil B	+	+	+	+
Soil C	+	+	+	+

Note: + = presence of organism.

Table 3a records the soil's physicochemical parameters. The pH ranged from 5.56 to 5.78, organic carbon (g/kg) ranged from 2.13 to 2.18, Ca (cmol/kg) ranged from 0.25 to 0.28, T.N (g/kg) ranged from 0.15 to 0.19, Ea (cmol/kg) ranged from 0.14 to 0.17, Silt (g/kg) ranged from 69 to 75, Mn (mg/kg) ranged from 0.56 to 0.63, and Fe (mg/kg) ranged from 46.87 to 51.2.

Table 3a. Results of the soil physicochemical analysis

Physicochemical parameters	A	B	C
pH	5.75	5.78	5.56
Organic carbon (g/kg)	2.13	2.15	2.18
Organic matter (g/kg)	3.62	3.70	3.78
Calcium (cmol/kg)	0.27	0.28	0.25
Magnesium (cmol/kg)	0.12	0.14	0.17
Sodium (cmol/kg)	0.23	0.26	0.36
Potassium (cmol/kg)	0.07	0.09	0.08
Average phosphorous (cmol/kg)	1.97	1.84	1.86
Total nitrogen (g/kg)	0.19	0.17	0.15
Cation exchange capacity (cmol/kg)	0.69	0.77	0.86
ECEC (cmol/kg)	0.83	0.94	1.02
Exchange acidity (cmol/kg)	0.14	0.17	0.16
Sand (g/kg)	820	822	810
Silt (g/kg)	69	70	75
Clay (g/kg)	98	101	108

Notes: sampling soil 1 is A; sampling soil 2 is B; sampling soil 3 is C.

Table 3b. Results of the heavy metal analysis

Heavy metals	A	B	C
Manganese (mg/kg)	0.56	0.59	0.63
Zinc (mg/kg)	1.23	1.56	1.78
Iron (mg/kg)	46.87	49.3	51.2
Copper (mg/kg)	0.78	0.78	0.82
Lead (mg/kg)	0.58	0.57	0.62
Chromium (mg/kg)	0.34	0.37	0.24
Cobalt (mg/kg)	0.08	0.08	0.09

Table 4 shows the biosorption process ranging from day 0 to day 5. The adsorption of CuSO_4 by *Staphylococcus* ranges from 5.11 day 0 to 3.88 day 5, of $\text{K}_2\text{Cr}_2\text{O}_7$ by *Bacillus subtilis* ranged from 4.08 day 0 to 3.20 day 5, of FeCl_3 by *Enterococcus faecalis* ranges from 5.14 day 0 to 4.86 day 5, of ZnSO_4 by *Escherichia*

coli ranges from 5.18 day 0 to 5.07 day 5, and consortium ranged from 5.21 day 0 to 4.64 day 5 for CuSO_4 .

Table 4. Biosorption of heavy metals by bacteria

	CuSO_4		$\text{K}_2\text{Cr}_2\text{O}_7$		FeCl_3		ZnSO_4	
	Day 0	Day 5	Day 0	Day 5	Day 0	Day5	Day 0	Day 5
EO1	5.11	3.88	4.33	3.09	5.07	4.11	5.21	4.55
EO2	5.54	3.91	4.08	3.20	4.90	3.61	5.36	4.25
EO3	5.30	5.13	4.31	4.10	5.14	4.86	5.33	4.49
EO4	5.56	5.11	4.20	4.03	5.18	5.07	5.17	4.82
Consortium	5.21	4.64	4.29	4.05	5.20	4.77	5.03	4.37

Notes: EO1: *Staphylococcus aureus*; EO2: *Bacillus subtilis*; EO3: *Enterococcus faecalis*; EO4: *Escherichia coli*; Consortium = EO 1+ EO2 + EO3 + EO4.

Table 5 shows the % of adsorption of CuSO_4 , $\text{K}_2\text{Cr}_2\text{O}_7$, FeCl_3 , and ZnSO_4 from day 0 to day 5 of the biosorption process. The percentage adsorption of CuSO_4 by *Staphylococcus* is 24.070, of $\text{K}_2\text{Cr}_2\text{O}_7$ by *Bacillus subtilis* is 21.568%, of FeCl_3 by *Enterococcus faecalis* is 5.447%, of ZnSO_4 by *Escherichia coli* is 6.769%, and of Consortium by CuSO_4 is 10.940%.

Table 5. Percentage adsorption of heavy metals

	CuSO_4	$\text{K}_2\text{Cr}_2\text{O}_7$	FeCl_3	ZnSO_4
E01	43.44	46.20	51.68	56.81
E02	59.03	47.55	60.61	62.87
E03	35.66	45.85	54.47	55.53
EO4	42.63	33.80	38.42	43.52
Consortium	53.17	53.15	43.08	53.50

Notes: EO1: *Staphylococcus aureus*; EO2: *Bacillus subtilis*; EO3: *Enterococcus faecalis*; EO4: *Escherichia coli*; Consortium = EO1 + EO2 + EO3 + EO4.

4. Discussion

As it was observed in this study, there are a few species of bacteria that can be found in the soil, and these include *Staphylococcus aureus*, *Bacillus subtilis*, *Enterococcus faecalis*, and *Escherichia coli*. The majority of these microorganisms have been linked to the solid waste condition and their biosorption capabilities [18]. Previous researchers indicated incompatible degrees of bacterial population in obstructed soils with solid wastes [19, 20]. Essentially the same organisms, such as *Bacillus*, *Enterobacter*, and *Staphylococcus* species, have been found in the solid waste dumpsites, which correlate with the results of the present study

[21]. The availability of the *Aeromonas*, *Neisseria*, *Klebsiella*, *Escherichia coli*, and *Serratia* species in the waste-contaminated soils was reported in other studies as well [22, 19]. The biodegradable portion of municipal solid waste dumpsites may have contributed to microbial increase and activities in soil [23]. The prevalence of the *Bacillus* species may be explained by the possibility to produce spores, which increases the survival and assimilation of metals when extreme environmental conditions are used [12]. Nevertheless, the excessive occurrence of these microbial isolates is a threat to the nation's health since most of them are pathogenic and can lead to disease outbreaks [20].

The pH of the soil was 5.56–5.78, indicating slightly acidic conditions. Such a pH may inhibit microbial growth and increase the mobility of heavy metals, thereby making more contaminants available for plant uptake or release into water bodies [24, 25]. The organic carbon level was 2.13–2.18 mg/kg, the organic matter was 3.62–3.78 mg/kg, and the C location contained the highest ones since the waste was deposited continuously [25]. The soil's electrical conductivity, which serves as an indirect indicator of salinity and as a significant measure of soil health, yielded high values throughout the dumpsites [11]. The measured values of calcium (0.25–0.28), total nitrogen (0.15–0.19), exchangeable acidity (0.14–0.17), as well as silt (69–75), manganese (0.56–0.63), and iron (46.87–51.2) were relatively high. Moderately acidic to nearly neutral pH was also reported to have positive effects on microbial activity, nutrient solubility, ionization, and enzymatic activity and to improve decomposition and nutrient levels [26]. These high values can be explained by the continuous deposition of solid wastes, which supports the previous reports [6, 12]. The build-up of heavy metals in food chains may lead to serious ecological and health-related problems in the environment and the population, such as skeletal defects, kidney diseases, or neurological problems [20, 27].

Trailer parks contain soils that may contain cadmium due to the release of the spent engine oil and the wear of the vehicle tires [28]. Cadmium has the ability to cause toxic effects in humans at the exposure levels that have been indicated [29]. Copper is a type of metal that is used most all over the world and is naturally available, although in the process of the anthropogenic activity it can reach toxic concentrations [1].

The application of individual and mixed bacterial cultures in the biosorption of CuSO_4 , $\text{K}_2\text{Cr}_2\text{O}_7$, FeCl_3 , and ZnSO_4 revealed different adsorption efficiencies. In the case of CuSO_4 , it was found that *Staphylococcus aureus*, *Bacillus subtilis*, *Enterococcus faecalis*, and *Escherichia coli* had biosorption efficiencies of 24.070, 29.422, 3.207, and 8.093% respectively. The direct interaction with *Bacillus subtilis*, rather than *Staphylococcus aureus*, could be caused by surface functional groups and spore-related attributes, and the low uptake by *Enterococcus faecalis* could be caused by the effects of surface charges [4, 5].

In the case of $K_2Cr_2O_7$, *Staphylococcus aureus* was found to be the best biosorber with a maximum biosorption of 28.637%, and *Bacillus subtilis* was the next good biosorber with 21.568% of biosorption. *Enterococcus faecalis* and *Escherichia coli* showed the lowest uptake of 4.872 and 4.047 respectively [5]. This implies that *Staphylococcus aureus* shows greater affinity towards chromium ions.

The percentage sorption efficiencies of the $FeCl_3$ biosorption of *Staphylococcus aureus*, *Bacillus subtilis*, *Enterococcus faecalis*, and *Escherichia coli* were 18.934, 26.326, 5.447, and 2.123 respectively. The excellent iron-binding capacity of *Bacillus subtilis* also encourages the selection of this microorganism in iron removal, and the low penetration into the *Escherichia coli* could be explained by the electrostatic repulsion [4, 5]. On the same note, the biosorption efficiencies of *Staphylococcus aureus*, *Bacillus subtilis*, *Enterococcus faecalis*, and *Escherichia coli* were found to be 12.667%, 15.759%, and 6.769% respectively. The results substantiate that microorganisms, especially *Bacillus subtilis*, are useful in the biosorption of the heavy gold in solid waste dumpsites [4, 5, 16].

5. Conclusions

The adsorption capacity of the solid waste dumpsites was best measured in relation to *Bacillus subtilis*, which was succeeded by *Staphylococcus aureus* and then *Enterococcus faecalis*. According to the results, *Bacillus subtilis* is found to be the viable bacterial isolate that can be used in the process of bioremediation and clean-up of heavy metals in solid waste dumpsites. It has a great sorption capacity, which implies it can withstand very unfavourable environmental conditions and is quite effective in removing the toxic metals in the polluted soils.

The paper also highlights that the bioremediation of microbes is a cost-effective and environmentally friendly way of dealing with heavy metal contamination in waste dumpsites. Indigenous bacteria like *Bacillus subtilis* that naturally occur in polluted soils are used, and remediation strategies are made sustainable, ensuring that they can be assimilated into the local ecosystems. In addition, the characteristics of these microorganisms in the simultaneous biosorption of different heavy metals suggest their ability to minimize environmental and health-related hazards around polluted waste soils.

Moreover, the physicochemical characteristics of the soils, such as pH, organic matter content, and electrical conductivity, were also found to influence the activity of microbes as well as the mobility of the heavy metals. Hence, bioremediation strategies could be carried out efficiently based on these soil parameters. Future research should be oriented towards the greater use of *Bacillus subtilis* in the field-scale remediation process and the development in the areas of synergy with alternative microbial species to optimize the removal of heavy metals in complex waste conditions.

References

- [1] Enerijiofi, K. E. (2021), Bioremediation of environmental contaminants: A sustainable alternative to environmental management. In: Saxena, Gaurav, Kumar, Vineet, P. Shah, Maulin (eds.), *Bioremediation for environmental sustainability: Toxicity, mechanisms of contaminants degradation, detoxification and challenges*. USA: Elsevier. 461–480.
- [2] Malidareh, H. B., Mahvi, A. H., Yunesian, M., Alimohammadi, M., Nazmara, S. (2014), Effect of fertilizer application on paddy soil heavy metals concentration and groundwater in North of Iran. *Middle-East Journal of Scientific Research* 20, 1721–1727.
- [3] Enerijiofi, K. E., Ikhajiagbe, B. (2021), Plant–microbe interaction in attenuation of toxic waste in ecosystem. In: Kumar, V., Prasad, R., Kumar, M. (eds.), *Rhizobiont in bioremediation of hazardous waste*. Singapore: Springer. 291–315. https://doi.org/10.1007/978-981-16-0602-1_13.
- [4] Ruiz-Manriquez, A., Magana, P. I., Lopez, V., Guzman, R. (2012), Biosorption of calcium by *Thiobacillus ferrooxidans*. *Bioprocess Engineering* 18, 113–118.
- [5] Kristanti, R. A., Hadibarata, T., Toyama, T. (2011), Bioremediation of heavy metals contaminated soil using microorganisms. *Journal of Environmental Protection* 2, 857–864.
- [6] Enerijiofi, K. E., Ekhaize, F. O. (2019), Physicochemical and microbiological qualities of government-approved solid waste dumpsites in Benin City. *Dutse Journal of Pure and Applied Sciences* 5(2a), 12–22.
- [7] Rajbansi, A. (2008), Study on heavy metal resistant bacteria of Gusehwori sewage treatment plant. *Our Nature* 6(1), 52–57.
- [8] Diaz, E. (2017), Bacterial bioremediation of heavy metals. *Journal of Environmental Biotechnology* 8(2), 45–53.
- [9] He, Z. L., Yang, X. E., Stoffella, P. J. (2011), Trace elements in agroecosystems and impacts on the environment. *Journal of Trace Elements in Medicine and Biology* 25, 1–14.
- [10] Nies, D. H. (2009), Microbial heavy metal resistance. *Applied Microbiology and Biotechnology* 51(3), 730–750.
- [11] Liyd, J. R. (2018), Bioremediation of metals: The application of microorganisms that make and break minerals. *Microbiology Today* 29(2), 67–69.
- [12] Enerijiofi, K. E., Ekhaize, F. O. (2019), Physicochemical and microbiological characterization of Edaiken and Santana market dumpsites soils in Benin City, Nigeria. *FULafia Journal of Science and Technology* 5(2), 136–149.
- [13] Tan, K. H. (2002), *Soil sampling, preparation and analysis*. Boca Raton, Florida: CRC Press.
- [14] Bouyoucos, C. J. (1951), Recalibration of the hydrometer method for making mechanical analysis of soils. *Agronomy Journal* 43(2), 434–438.

- [15] Day, P. R. (1965), Particle fractionation and particle-size analysis. In: Black, C. A. (ed.), *Methods of Soil Analysis*. American Society of Agronomy. 545–567.
- [16] Ahalya, N., Ramachandra, T. V., Kanamadi, R. D. (2003), Biosorption of heavy metals. *Research Journal of Chemistry and Environment* 7(4), 71–79.
- [17] APHa (2017), *Standard methods for the examination of water and wastewater* (23rd ed.). Washington, DC: American Public Health Association.
- [18] Obire, O., Akinde, S. B., Adedokun, O. M. (2002), Microbial population of waste dump sites. *Journal of Applied Sciences and Environmental Management* 6(1), 78–83.
- [19] Oviasogie, F. E., Ajuzie, C. U., Uyiosa, G. I. (2010), Bacterial analysis of soil from waste dumpsites. *Archives of Applied Science Research* 2(5), 161–167.
- [20] Enerijiofi, K. E., Ajuzie, C. U. (2012), Health impact of some heavy metal resistance in microbes isolated from Ikhueniro refuse dumpsite, Benin City. *Nigerian Journal of Microbiology* 26(5), 2592–2598.
- [21] Osazee, O. J., Okhuoya, J. A., Ehigie, L. O. (2013), Microbial diversity and physicochemical characteristics of soils from municipal solid waste dumpsites. *Journal of Applied Sciences and Environmental Management* 17(4), 563–569.
- [22] Achudume, A. C., Olawale, J. T. (2007), Microbial pathogens of public health significance in waste dumps and surrounding soils. *African Journal of Environmental Science and Technology* 1(6), 138–144.
- [23] Ogwueleka, T. C. (2009), Municipal solid waste characteristics and management in Nigeria. *Iranian Journal of Environmental Health Science & Engineering* 6(3), 173–180.
- [24] Olatunde, K. A., Akinyemi, O. A., Oyekanmi, A. A. (2020), Influence of soil pH on heavy metal mobility and bioavailability in contaminated soils. *Environmental Monitoring and Assessment* 192, 1–11.
- [25] Adedeji, O. H., Olayinka, O. O., Tope-Ajayi, O. O. (2020), Effects of municipal solid waste dumps on soil physicochemical properties and heavy metal distribution. *Environmental Challenges* 1, 100004.
- [26] Voroney, R. P. (2007), The soil habitat. In: Paul, Eldor A. (ed.), *Soil microbiology, ecology and biochemistry* (3rd ed.). Elsevier Academic Press. 25–49.
- [27] Atalia, K. R., Patel, A. P., Patel, K. C. (2015), Heavy metal contamination in soil and its impact on human health. *International Journal of Research in Environmental Science* 1(2), 17–24.
- [28] Courtney, R., Mullen, G. (2008), Soil quality and heavy metal accumulation in reclaimed waste dumpsites. *Environmental Pollution* 156(3), 889–898.
- [29] Amouei, A., Fallah, S. H., Asgharnia, H. A., Naddafi, K. (2018), Health risk assessment of cadmium exposure through contaminated soils. *Human and Ecological Risk Assessment* 24(5), 1231–1245.